Earth Science Futuristic Trends and Implementing Strategies

Shahid Habib
NASA
Goddard Space Flight Center
Greenbelt, Maryland 20771, USA
Shahid.Habib-1@nasa.gov

***Abstract*: For the last several years, there is a strong trend among the science community to increase the number of space-based observations to get a much higher temporal, spectral and spatial resolution. Such information will eventually be useful in higher resolution models that can provide predictability with higher precision. Such desirability puts a tremendous burden on any single implementing entity in terms of budget, technology readiness and compute power. The health of planet Earth is not governed by a single country, but in reality, is everyone's business living on this planet. Therefore, with this notion, it is becoming an impractical problem by any single organization/country to undertake. So far, each country per their means has proceeded along satisfactorily in implementing or benefiting directly or indirectly from the Earth observation data and scientific products. However, time has come that this is becoming a humongous problem to be undertaken by a single country. Therefore, this paper gives some serious thoughts in what options are there in undertaking this tremendous challenge. The problem is multi-dimensional in terms of budget, technology availability, environmental legislations, public awareness, and communication limitations. Some of these issues are introduced, discussed and possible implementation strategies are provided in this paper to move out of this predicament. A strong emphasis is placed on international cooperation and collaboration to see a collective benefit for this effort.**

I. BACKGROUND

The world has made a tremendous progress in the last three decades in space-based earth observing systems. The researchers have been investigating science questions/phenomena by deploying single platform missions in space for the last number of years. Such platforms have normally been multi-instrument satellites with multiple science objectives. Traditionally, National Aeronautics and Space Administration (NASA) in conjunction with other US Government Agencies such as National Oceanic and Space Administration (NOAA) and United States Geological Survey (USGS) have built many large platform missions for Earth science research. For example, Nimbus, Landsat, Polar-Orbiting Operational Environmental Satellite (POES), Upper Atmospheric Research Satellite (UARS), Terra and recently launched Aqua, Environmental Satellite (Envisat) by European Space Agency (ESA), and Meteor and Resurs series by the Russian Aviation and Space Agency (RASA) fall under the large platform classification. These satellites carried many instruments including UV, Visible, IR, microwave and radio frequency spectral bands. If one in retrospect analyzes an integrated development life cycle for any of these platforms, it is anywhere from 7-10 years and nearly half a billion real year dollars. At the same time, let's not forget a large infrastructure cost on the ground in terms of ground communication network and computational facilities. The idea here is not to play down the important contributions being made by such space assets, but to learn critical lessons in order to take advantage of emerging technologies to meet the future scientific measurement needs. However, the cost of deploying multiple sensors to meet the future science needs is becoming unaffordable for any single entity or a country to bore. If the benefit of this research is to serve the habitants of this planet then this responsibility must be shared by all nations. Although there has been a tremendous work done by relatively rich countries in the area of Earth science research, but it is fragmented and meets each individual countries scientific desires and priorities as opposed to the global agenda. In reality, there is no global mechanism in place that will mandate an integrated observing systems and strategy for the entire globe with each participant bearing their share. The question arises, how should this be done? This is especially of greater interest when the future science requirements call for multiple platforms and sensor webs [1] for making such demanding measurements. The following sections discuss earlier and future models to envisage some implementation concepts.

II. WHY ADDITIONAL OBSERVATIONS

One can see the early requirements concentrated on relatively simple measurements such as visible bands, UV spectroscopy and atmospheric temperature profiling. As technology improved, additional measurements to map the land and ocean surfaces were introduced. This pattern has continued to date in order to measure many more geological and atmospheric features from space (e.g., soil moisture, ocean salinity, tropospheric winds, Earth's seismographic information and many more).

At this time measurements regarding ozone, moisture, temperature, ocean surface, land surface variations, solar cycle, ocean surface winds, and oceanic ice are underway. However, the frequency, temporal coverage, modeling and computational needs fall short of generating medium to long-term predictions with high level of confidence. This problem is compounded when we talk about short-term predictions that influence our planet's diurnal cycle. Similarly, the accuracy of long-term predictions is imperative since these are key inputs in making policy decisions such as control of hydrocarbons and aerosols in the troposphere. These goals may be achievable provided there is continuous influx of measuring and observing technologies and the supporting computational power to bring these to a realization. In order to deploy additional space, ground and air borne sensors, clear and tangible reasons are needed and their expenses must be justified.

III. EARLY IMPLEMENTATION MODEL

The existing Earth observing systems were primarily conceived by operational needs with a strong tie to the weather satellites. In the US, the weather satellites have played a profound role in exposing some key phenomena ranging from El Nino to the impact of ozone and many additional parameters. Additionally, these satellites have also carried land-imaging sensors that have provided a wealth of data on the vegetation changes, rock formation and erosion patterns and hydrology. These satellites were developed by the US Government and to date have been operated by the Governmental Agencies as well. Lately, the focus is starting to shift towards commercial providers of remote sensing data. This is particularly applicable to the land imaging because of its strong connection with the commercial market to aid in the field of urban planning, disaster management and forestry. These satellites are designed with 1 m resolution to be useful for commercial use. In spite of such advancements, the brunt of science responsibilities still falls back in the Governmental sector. This is normally true for all the G8 countries involved in the Earth science research. For the last decade or so, Russia is also following the same model as the G8 nations.

Since the science is the key driver in understanding and explaining the chaotic, nonlinear nature of the planet Earth's behavior, NASA took a leadership role in defining the Earth Observing System (EOS) program in the mid 1980s. This multi billion-dollar commitment put a tremendous burden on any single country's budget to engage in such a giant endeavor. Although, there have been a number of international participants in providing instruments and occasional launches, but the major responsibility lied within the NASA/US domain. Similarly, the other nations have pretty much tried to duplicate the same NASA model.

The individual implementation models have made a great strive in science and technology and have led many discoveries relating oceanography and stratospheric chemistry. However, none of these achievements have been cheaper. Fig. 1 shows a cost growth of NASA directed missions. The early years show a relatively smaller cost until the initiation of EOS program. This was a major demarcation in the Earth science research for NASA and the world because it set the pace for several countries to follow this model.

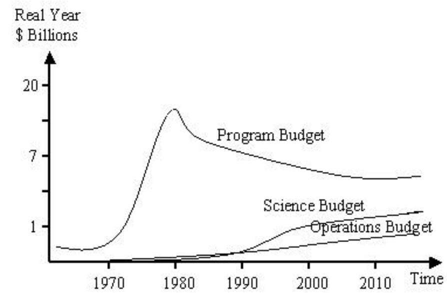

Figure 1. A large program budget profile.

IV. PRESENT MODEL

About 1990s the program focus shifted towards discovery and curiosity science research. The science was divided into several key areas such as Atmospheric chemistry, solid Earth, weather and climate variability and change. These science areas, to a greater extent, have been self imposed and set the implementation standards rather on a high side (such as tropospheric gases from space with high resolution or measuring OH radical in the stratosphere). These requirements have presented a significant technological challenges and heavy budgetary investments. In reality, the technology development should have not been intrinsically included inside the mission life cycles. This has put a tremendous burden on the budget and has contributed to launch delays occasionally. At the same time the new measurements have generated terabytes of data, which has overwhelmed the existing compute power. So, the outstanding question is, what is the best fit that balances between technology, cost and user needs. Some of these questions have not been paid much attention until recently. This in fact requires constraining the problem under consideration and then carefully examining the trade space and then optimizing the solution. Fig. 2 illustrates this point by showing a migration from "free research" to a more "bounded research." Therefore, in order to tackle the pressing science needs one has to examine the future implementation strategies much more cleverly.

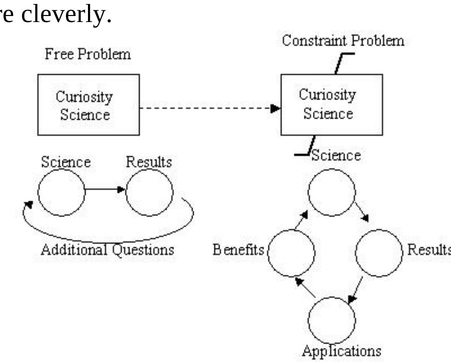

Figure 2. Migrating from free to a constraint problem.

The legislators have also shown whether there are enough set of smart eyes through out the country to analyze and decipher all this data for scientific use and socio-economic benefit. The complexity of problem has grown many folds: 1) more measurements 2) more data 3) higher resolution 4) high fidelity models 5) higher data frequency and 6) coupling of models to study an integrated problem. As mentioned above, another serious issue which recently been emerging to surface is what are the benefit of all this investment that can do some good to common public. In reality, this constraint has become a significant matter in justifying funds for future science observations since the focus has shifted from an open form of curiosity science to a constrained research. This further translates into what are the benefits from all this Earth science research if this is chartered to help the mankind in the first place. This is a very difficult argument to defeat. Fig. 3 clearly illustrates this point by striking a balance between science, technology and socioeconomic benefits. The budgets will be more closely scrutinized in the future years and they may stay flat or have a miniscule growth. Therefore, it is imperative that the practitioners of the discipline of Earth science think new ways to implement their future requirements and missions. The underline message here is not all that negative. However, it is a paradigm shift in our ways of thinking, implementing and managing.

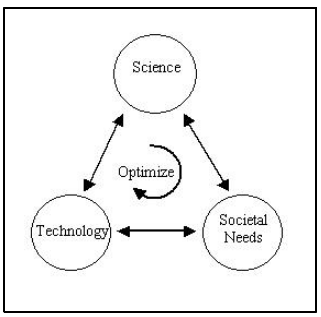

Figure 3. Balancing science for society.

V. FUTURE MODEL

The future implementation strategies must take into consideration a multitude of things leading towards a common set of goals such as:

- Study of planet Earth as a system
- Resource pooling
- Global integrated observing strategy
- Sharing and dissemination of technology, data, results and products in an open and a timely manner
- Educating public the importance of Earth science research
- Carefully examining the commercial remote sensing entities versus Governmental funded operations
- Finding a right balance between the in situ versus space based measurements
- Categorization of problems by certain priority i.e., long term research priorities may be different then the near term application needs.

Keeping the above goals in mind, it is evident that one country cannot undertake the entire research discipline and its implementation responsibilities. The budget and the technical expertise are limited to embark on such large commitments. At the same time, it also does not make sense since today's problems are global (e.g., air pollution transport) and are independent of geographical boundaries. Therefore, the sharing and caring is a common denominator in this complicated area of research and is a very fundamental one to its success. However, it is everyone's responsibility to maintain the health of this planet. It is an international issue and it should be handled with a greater rigor, commitment and ownership. The present framework under the Committee of Earth Observing Satellites (CEOS) does offer a loose coordinating function [2]. Therefore, an international forum should be established that should be responsible for making investment decisions at the international level. This forum should be charged with the following responsibilities:

- An authoritative international body jointly responsible for implementing the Earth science research program headed under the leadership of G8 nations, as shown in Fig. 4
- All member countries pool their resources to implement a set of joint priorities as established by global needs
- The budgetary commitments by each individual country should be fixed for a five-year period
- The nations who do not have the technology or expertise should provide funds to be a bonafide member
- Poor nations can be granted a special status to ensure that they are engaged in educating their masses.

This model may be difficult to implement because of political and competitive boundaries. However, it's main advantages will be eliminating an implementation burden from a single country, and provide many more observations or sensor webs for future science and applications.

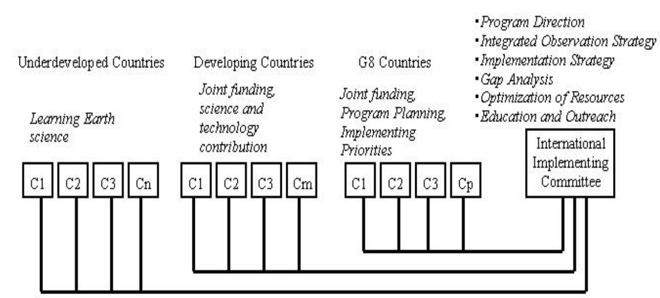

Figure 4. International implementation committee

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[2] Committee on Earth Observation Satellite Handbook (2002), CEOS Secretariat, European Space Agency, Paris, France.